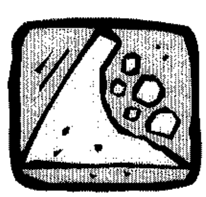
5.5 Geology and Soils

The CALFED Bay-Delta Program would result in overall benefits to geomorphological characteristics and soils throughout the Program study area. Construction would result in some short-term impacts that would cease when construction was complete.



5.5 Geology and Soils

5.5.1 SUMMARY

Over the eons, water and wind have helped carry sediment and debris downstream. During floods, much of that sediment was redistributed over the Central Valley floor, providing excellent conditions for agriculture. Urbanization, agricultural practices, and flood control facilities have affected some historical trends. However, the rich soils and unique geological resources in the CALFED Bay-Delta Program (Program) study area continue to influence human activities and contribute to the quality of life.

Sediment that was redistributed over the Central Valley floor during floods provided excellent conditions for agriculture.

Preferred Program Alternative. Geology and soils would benefit from many of the Program elements. The Ecosystem Restoration Program, in restoring wetland and wildlife habitat, could lessen soil depletion and wind erosion on Delta islands. By improving water quality, the Water Quality Program could reduce soil salinity, selenium concentrations, and sediment contamination. The Levee System Integrity Program could decrease subsidence on Delta islands. The overall long-term benefits from the Program generally outweigh the short-term potentially significant impacts, many of which can be mitigated to a less-than-significant level. Short-term construction-related impacts associated with the Preferred Program Alternative likely would be less than significant and would cease when construction was completed. Ground disturbance and innundation caused by the construction of new storage facilities is considered potentially significant. Changes in downstream geomorphology that would result from expanding existing storage facilities also is considered potentially significant.

Alternatives 1, 2, and 3. Alternatives 1, 2, and 3 would result in similar benefits and adverse impacts as those described for the Preferred Program Alternative. The Preferred Program Alternative and Alternatives 2 and 3 have greater potential for short-term construction-related impacts than Alternative 1 because of their additional Conveyance elements. However, these alternatives also could result in greater long-term benefits, such as reduced erosion, restored wildlife habitat, and improved water quality. Conversely, Alternative 1 could result in the least amount of short-term impacts but also would provide the least amount of overall long-term benefits.

The following table presents the potentially significant adverse impacts and mitigation strategies associated with the Preferred Program Alternative. Mitigation strategies that correlate to each listed impact are noted in parentheses after the impact.

Potentially Significant Adverse Impacts and Mitigation Strategies Associated with the Preferred Program Alternative

Potentially Significant Adverse Impacts

Increased conversion of agricultural land soils for levee system construction and increased potential for erosion on outboard slope of levees (3,4,5,6,8,9,14, 15,16).

Potential for increases in local subsidence from potential increased reliance on groundwater use (1,2).

Potential for increases in wind and soil erosion and in soil salinity due to fallowed agricultural lands (4,9, 10,11).

Increased construction-related short-term soil erosion, and increased sediment deposition or soil compaction from heavy equipment (4,5,6,8,13,14,16).

Potential changes to downstream geomorphology from enlarging existing storage facilities (6,7,8,12, 17,18).

Ground disturbance, inundation, and shoreline wind- and wave-generated erosion from new storage facilities (4,5,6,14,16,19).

Mitigation Strategies

1. Monitoring groundwater levels and subsidence in areas of increased reliance on groundwater resources and regulating withdrawal rates at levels below those that cause subsidence.

2. Minimizing or avoiding direct groundwater transfers or groundwater substitution transfers from regions: (1) experiencing long-term overdraft, (2) where subsidence historically has occurred, or (3) where local extensometers indicate that subsidence rates are increasing.

3. Protecting flooded Delta island inboard levee slopes against wind and wave erosion with vegetation, soil matting, or rock.

4. Protecting exposed soils with mulches, geotextiles, and vegetative ground covers to the extent possible during and after project construction activities in order to minimize soil loss.

5. Implementing erosion control measures and bank stabilization projects where needed.

6. Increasing sediment deposition and providing substrate for new habitat by planting terrestrial and aquatic vegetation.

7. Measuring channel morphology over time to monitor changes and implementing erosion control measures where needed.

8. Re-using dredged materials to reduce or replace soil loss.

9. Leaving crop stubble from previous growing season in place while fallowing and employing cultivation methods that will cause the least amount of disturbance in order to minimize erosion of surface soils.

10. Limiting the salinity of replacement water, relative to local conditions, in water transfers.

11. Ensuring that the volume of irrigation water used is sufficient to flush accumulated salts from the root zone.

12. Operating new storage facilities to minimize sediment trapping and transport in rivers and tributaries.

13. Retrofitting soil-comprised structures to seismic events with shock-absorbing devices and materials in areas of seismic vulnerability, wherever possible.

Potentially Significant Adverse Impacts and Mitigation Strategies Associated with the Preferred Program Alternative (continued)

14. Preparing and implementing best construction management plans.

15. Preparing and implementing a water quality and soils monitoring program.

16. Preparing and implementing construction mitigation plans.

17. Preparing and implementing contingency plans for wetland and marshland restoration.

18. Modifying storage facility operations to maintain variability in downstream flow rates.

19. Controlling boat traffic in order to reduce boat wakes to levels that will not cause levee or bank erosion.

No potentially significant unavoidable impacts on geology and soils are associated with the Preferred Program Alternative.

5.5.2 AREAS OF CONTROVERSY

Controversy exists about the Water Use Efficiency Program reducing applied water to agricultural lands in the Sacramento River basin.

Areas of controversy as defined by CEQA involve differences of opinion among technical experts or information that is not available and cannot be readily obtained. According to this definition, no areas of controversy relate to geology and soils.

Some controversy exists, however, about the Water Use Efficiency Program reducing applied water to agricultural lands in the Sacramento River basin, which in turn could increase the amount of residual salts in the soil and degrade agricultural productivity. Retiring drainage-impaired agricultural land to reduce selenium and salt loadings in the San Joaquin River could result in increased soil erosion due to wind and runoff. Other concerns have been generated by the Storage Program. A concern exists that off-stream storage facilities could alter sediment transport by potentially trapping sediments, reducing sediment transport, increasing stream erosion, and altering geomorphologic characteristics downstream of the storage facility.

At the programmatic level of analysis, these areas of concern are addressed qualitatively in the following analysis. The Program would result in an overall beneficial effect on soil salinization and erosion. Additionally, the Program would result in a beneficial effect on channel erosion, sedimentation, and geomorphologic characteristics due to changes on land surfaces. These issues will be addressed and analyzed further as specific projects are proposed to carry out the Preferred Program Alternative.

5.5.3 AFFECTED ENVIRONMENT/ EXISTING CONDITIONS

Different geologic processes acting on various rock formations over millions of years have created many geologically different areas in California.

Key resource categories and assessment variables described in this section include geology and physical processes; fluvial geomorphology, especially erosion and sedimentation;

oxidation, wind erosion, and land subsidence; soil salinity and drainage problems; and seismicity.

Overview. Different geologic processes acting on various rock formations over millions of years have created many geologically different areas in California. The areas have been grouped into 11 geologic provinces. From north to south, they are the Coast Ranges, Klamath Mountains, Cascade Range, Modoc Plateau, Central Valley, Sierra Nevada, Basin and Range, Mojave Desert, Transverse Ranges, Peninsular Ranges, and the Salton Trough. The study area for this investigation includes all of the provinces mentioned, except the Basin and Range, and Salton Trough. Figure 5.5-1 shows all the geologic provinces in the state. The Central Valley Geological Province is a valley trough that extends over 400 miles from north to south and consists of the Sacramento Valley and the San Joaquin Valley. The San Joaquin Valley is comprised of the San Joaquin River basin, drained by the San Joaquin River from the south, and the Tulare basin, a hydrologically closed basin that is drained only during extremely wet periods. The Sacramento Valley is drained by the Sacramento River from the north. The confluence of these two major river systems and lesser streams and systems forms the inland Delta, which is drained through Suisun Bay and the narrow Carquinez Strait into San Pablo and San Francisco Bays—and into the Pacific Ocean.

The Central Valley Geological Province is a valley trough that extends over 400 miles from north to south and consists of the Sacramento Valley and the San Joaquin Valley.

The upper and lower watersheds of the area contain four primary physiographic land types, each with characteristic soil conditions: valley land, valley basin land, terrace land, and upland (Figure 5.5-2). Valley land and valley basin land soils occupy most of the Central Valley floor. Valley land soils consist of deep alluvial and aeolian soils that make up some of the best agricultural land in the state. Valley basin lands consist of organic soils of the Sacramento-San Joaquin Delta, poorly drained soils, and saline and alkali soils in the valley trough.

The upper and lower watersheds of the area contain four primary physio- graphic land types, each with character- istic soil conditions: valley land, valley basin land, terrace land, and upland.

Areas above the Central Valley floor consist of terrace and upland soils, which are primarily used for grazing and timberland.

Existing soils and the geomorphology of streams in the upper watersheds of the Bay Region mainly show the effects of urbanization, whereas these same resources in the upper watersheds of the Sacramento River and San Joaquin River Regions primarily are influenced by grazing and logging.

5.5.3.1 DELTA REGION

The Delta, a triangular-shaped network of channels and islands, is the meeting point for the Sacramento, San Joaquin, and Mokelumne Rivers. The Delta islands have been reclaimed for agricultural use because of their fertile soils. Conversion of the Delta wetlands to farmlands began in 1850 when the federal government transferred ownership of "swamp and overflow" lands to the states. Substantial reclamation was accomplished

The Delta, a tri- angular-shaped network of channels and islands, is the meeting point for the Sacramento, San Joaquin, and Mokelumne Rivers.

Source: California Division of Mines and Geology 1966

Figure 5.5-1. Geologic Provinces of California

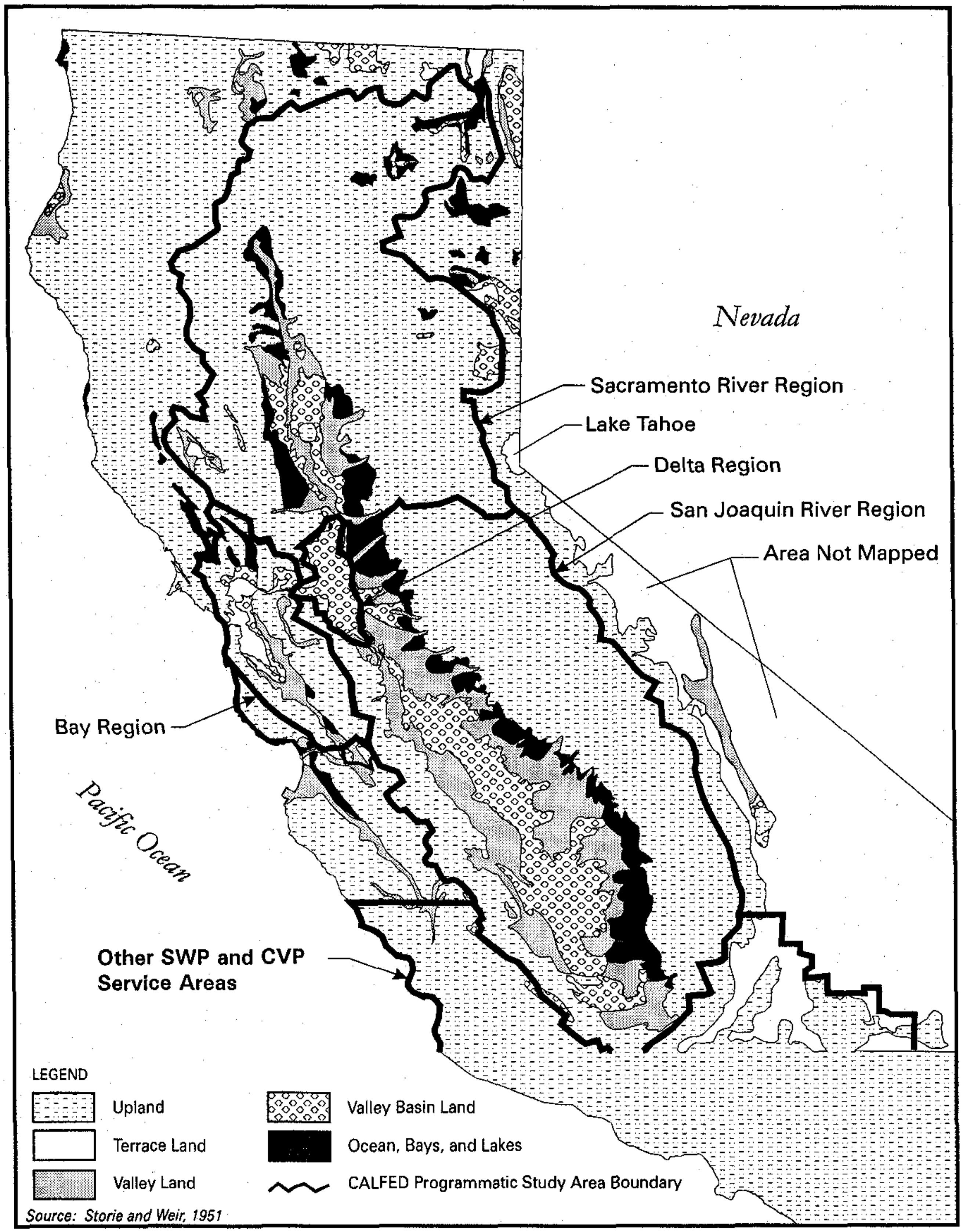


Figure 5.5-2. Generalized Soils of California

between 1880 and 1920. By 1930, the Delta essentially was developed to its current configuration.

By 1920, it was recognized that the drained Delta lands were subsiding. Elevation measurements made from 1922 to 1981 indicate that land use practices on peat soils (organic or highly organic mineral soils) tended to cause from 1 to 3 inches of subsidence per year.

Soils. The soils of the Delta Region vary primarily as a result of differences in geomorphological processes, climate, parent material, biologic activity, topography, and time. For this discussion, the soils are divided into four general soil types:

- Delta organic soils and highly organic mineral soils
- Sacramento River and San Joaquin River deltaic soils
- Basin and basin rim soils
- Moderately well- to well-drained valley, terrace, and upland soils

The Delta Region contains primarily soils with the required physical and chemical soil characteristics, growing season, drainage, and moisture supply necessary to qualify as prime farmland. This includes 80-90% of the area of organic and highly organic mineral soils, Sacramento River and San Joaquin River deltaic soils, and basin and basin rim soils. Most of the remaining soils of the Delta Region qualify as farmland of statewide importance.

The Delta soils that have been most affected by agricultural development are the organic soils and highly organic mineral soils. These effects are caused by the flood protection of levees and the lowering of water tables by pumps and drainage ditches in order to make production possible.

Soil Subsidence. Subsidence of the Delta's organic soils and highly organic mineral soils (Figure 5.5-3) continues to be a concern and could present a threat to the present land use of the Delta islands.

Interior island subsidence is attributable primarily to biochemical oxidation of organic soil material as a result of long-term drainage and flood protection. The highest rates of subsidence occur in the central Delta islands, where organic matter content in the soils is highest.

Interior island subsidence is attributable primarily to biochemical oxidation of organic soil material as a result of long-term drainage and flood protection.

Development of the islands resulted in subsidence of the island interiors and greater susceptibility of the topsoil to wind erosion. Subsidence, as it relates to Delta islands, refers generally to the falling level of the land surface that results primarily from the process of peat soil oxidation. Levee settlement may be partially caused by peat oxidation if land adjacent to levees is not protected from subsidence.

Delta Seismicity. The primary seismic threat to the Delta is levee failure resulting from lateral displacement and deformation, with resultant breaching or mass settlement due to

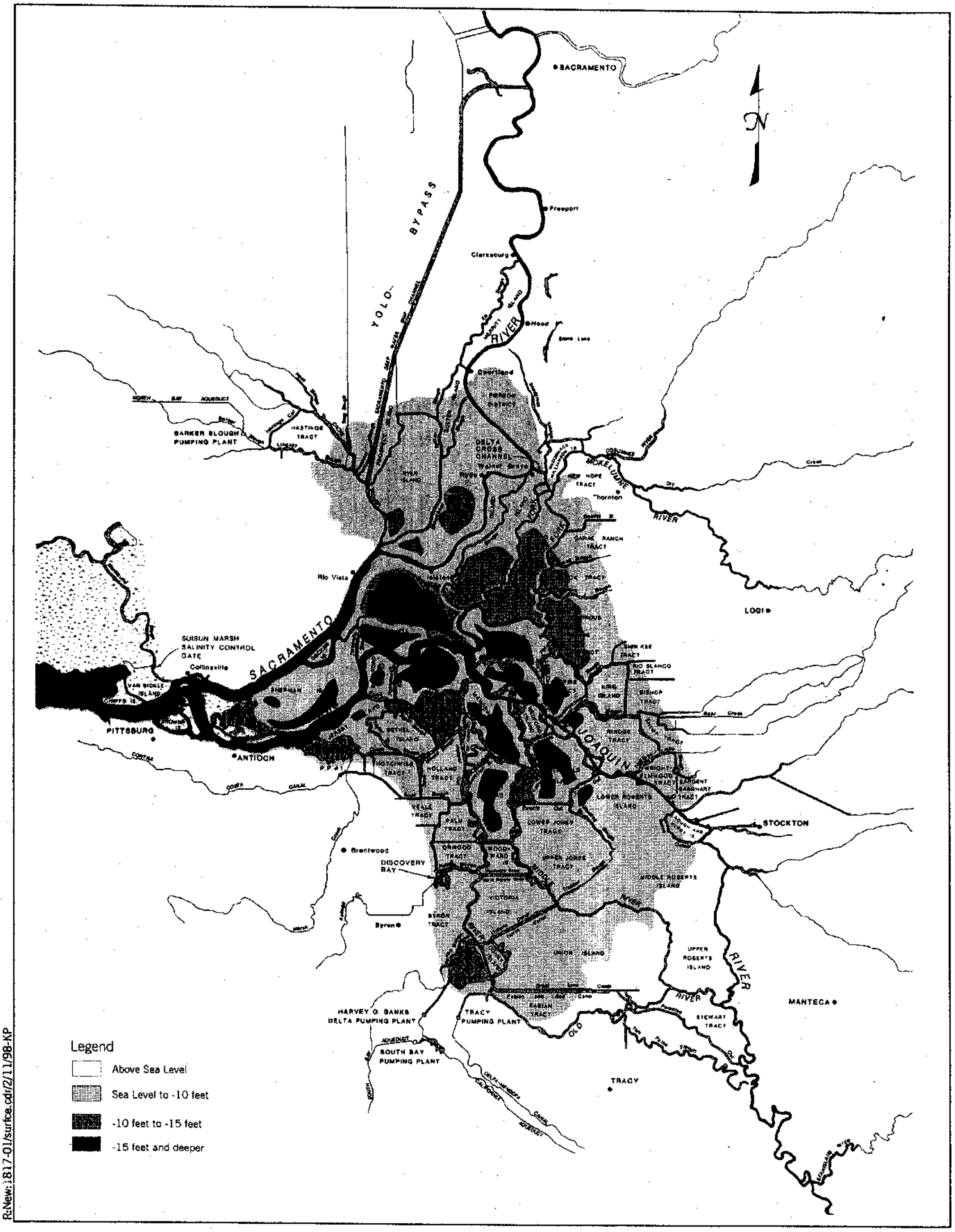


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Figure 5.5-3. Land Surface below Sea Level in the Delta ground shaking and liquefaction of levee materials. Many levees include sandy sections with low relative density and high susceptibility to liquefaction. Therefore, the seismic risk to Delta levees varies significantly across the Delta, depending on the proximity to the source of the earthquake and the conditions of the levee and levee foundation.

A review of available historical information indicates that little damage to Delta levees has been caused by historical earthquakes. No report could be found to indicate that an island or tract had been flooded due to an earthquake-induced levee failure. Further, no report could be found to indicate that significant damage had ever been induced by earthquake shaking. The minor damage that has been reported has not significantly jeopardized the stability of the Delta levee system.

This lack of severe earthquake-induced levee damage corresponds to the fact that no significant earthquake motion has apparently ever been sustained in the Delta area since the construction of the levee system approximately a century ago. The 1906 San Francisco earthquake occurred 50 miles to the west, on the San Andreas Fault, and produced only minor levels of shaking in the Delta. As the levees were not yet very tall in 1906, these shaking levels posed little threat. Continued settlement and subsidence over the past 90 years and the increasing height of levees needed for flood protection have, however, substantially changed this situation. Consequently, the lack of historical damage to date should not lead, necessarily, to a conclusion that the levee system is not vulnerable to moderate-to-strong earthquake shaking. The current levee system simply has never been significantly tested.

The lack of severe earthquake-induced levee damage corresponds to the fact that no significant earthquake motion has apparently ever been sustained in the Delta area since the construction of the levee system approximately a century ago.

The Delta levees are located in a region of relatively low seismic activity compared to the San Francisco Bay Area. The major strike-slip faults in the Bay Area (San Andreas, Hayward, and Calaveras Faults) are located over 16 miles from the Delta Region. The less active Green Valley and Marsh Creek-Clayton Faults are over 9 miles from the Delta Region. Small but significant local faults are situated in the Delta Region, and there is a possibility that blind thrust faults occur along the west Delta.

Soil Salinity. Increasing soil salinity has been recognized as a problem in the San Joaquin Valley since the late 1800s, when a rapid increase in irrigated acreage coincided with increasingly poor drainage (due to elevated shallow groundwater table levels) and elevated soil salinity levels in the western and southern portions of the San Joaquin Valley.

Dissolved salts in irrigation water can lead to high soil salinity, an unfavorable condition for agricultural crop production. High soil salinity is an issue in several portions of the Delta, including the south Delta area, the west Delta area (primarily Sherman and Twitchell Islands), and Suisun Marsh. North and east Delta areas receive relatively low-salinity water from the Sacramento River and east side tributaries, and do not experience salinity problems.

The concentration of salinity in shallow groundwater and the salt mass contained in Delta soils are direct consequences of the quality of the irrigation water drawn from Delta channels.

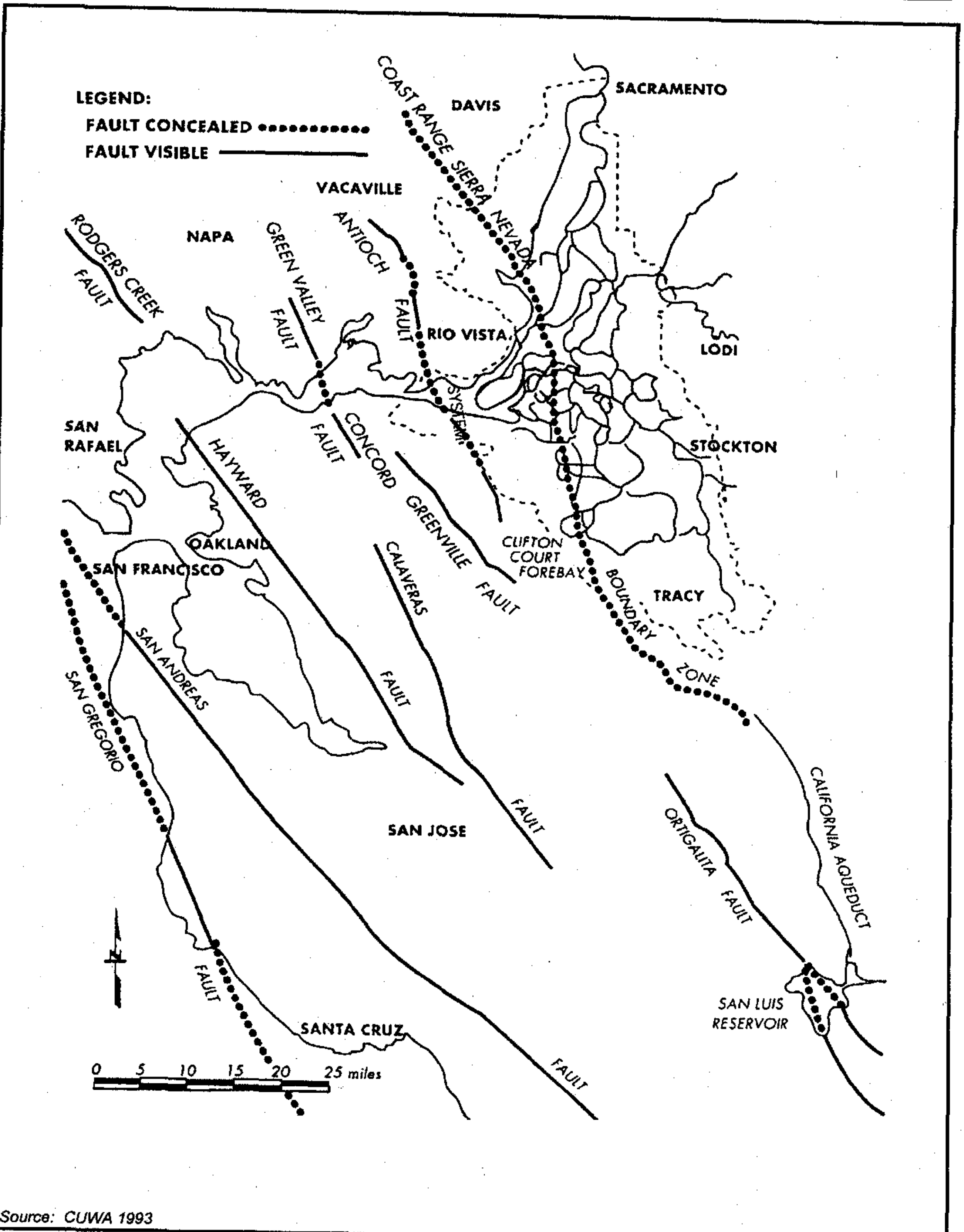

Figure 5.5-4. Faults within and near the Delta

Wind Erosion. The Delta organic soils and highly organic mineral soils have wind erodibility ratings of 2-4 on a scale where 1 is most erodible and 8 is least erodible. The high wind erodibility of Delta soils is due to their organic matter content. The rate of wind erosion is estimated at 0.1 inch per year.

Sedimentation and Fluvial Erosion in the Delta. The great quantities of sediment transported by the rivers into the Delta move primarily as suspended load. Of the estimated 5 million tons per year of sediment inflow into the Delta, about 80% originates from the Sacramento River and San Joaquin River drainages; the remainder is contributed by local streams. Approximately 15-30% of the sediment is deposited in the Delta; the balance moves into the San Francisco Bay system or out through the water project facilities.

Sediment circulation within the Bay-Delta system is complex due to the numerous interconnected channels, tidal flats, and bays, within which the interaction of fresh-water flows, tides, and winds produce an ever-changing pattern of sediment suspension and deposition. Pumping at the CVP and SWP Delta facilities alters this circulation of sediments within the system and may cause erosion of the bed and banks by inducing higher water velocities in the channels.

Sediment circulation within the Bay-Delta system is complex due to the numerous interconnected channels, tidal flats, and bays, within which the interaction of fresh-water flows, tides, and winds produce an ever-changing pattern of sediment suspension and deposition.

The mechanics of sediment transport in either saline or tidally affected streams, such as the lower Sacramento River and the Delta, are even more complex than in fresh-water streams. This complexity results from changes in flow velocity, flow direction, and water depth caused by the tides. The Delta is primarily a depositional environment, but variations in water and sediment inflow result in either erosion or deposition.

Erosion may occur when (1) the velocity of flow in a channel is increased, (2) the sediment inflow to a channel in equilibrium is reduced, or (3) predominance of flow in one direction is altered in a channel that experiences reverse flows. The actual rate of erosion depends on the composition of the material on the bed and banks, and on the amount of change in the factors listed previously.

Deposition is induced when conditions are the opposite of those favorable for erosion. The rate of deposition depends on the type and amount of sediment in suspension, the salinity, and the extent to which the transport capacity of the channel has been changed by reduction in flow velocity and channel size. Increasing salinity causes the suspended load of clay and silt particles to form aggregates that settle and deposit more rapidly than individual sediment particles. Deposition near Rio Vista may be caused by the convergence of the Sacramento River with the Deep Water Channel, forming a wider channel with resultant lower water velocities.

Flows induced by use of the DCC have affected the North Fork of the Mokelumne River by eroding a rather deep channel near New Hope, thereby accelerating the need for riprap on the Mokelumne River levees. DCC flows that go down the South Fork pass through Dead Horse Cut and impinge on the Staten Island levee at a right angle, resulting in erosion of the bank in this area.

The discharges and velocities in the channels south of the San Joaquin River are influenced significantly by exports at the CVP and SWP pumping plants. Sediment deposition and gain from local drainage alter the amount and composition of the sediment transported in the channels. In addition, degradation or aggradation, and widening or narrowing of certain channels may be occurring due to the higher velocities caused by pumping.

5.5.3.2 BAY REGION

The Bay occupies a structural trough that formed during the late Cenozoic when it was part of a great drainage basin of the ancestral San Joaquin, Sacramento, and Coyote Rivers. The Bay was formed between 10,000 and 25,000 years ago, when the polar ice caps melted at the end of the fourth glacial period. Sea level rose in response to the melting of the ice caps. As the ocean rose, it flooded river valleys inland of the Golden Gate, forming San Francisco Bay, San Pablo Bay, and Suisun Bay.

The Bay occupies a structural trough that formed during the late Cenozoic when it was part of a great drainage basin of the ancestral San Joaquin, Sacramento, and Coyote Rivers.

Geographically, the Suisun Marsh is located in the Bay Region. For most resources, the only Program actions that would directly affect the marsh are levee improvements under the Levee System Integrity Program and restoration actions under the Ecosystem Restoration Program.

Soils and Sediment Conditions. The sediments of the shallows comprise silty clay, clayey silt, and sand-silt-clay, while sand and silty sand cover the deeper areas of the Central Bay and San Pablo Bay. Gravelly sands are found at Golden Gate and grade seaward to a well-sorted sand that covers most of the intercontinental shelf region of the Gulf of Farallons.

The Bay Region can be divided into four major landform types (each with characteristic soils): (1) basin floor/basin rim, (2) floodplain/valley land, (3) terraces, and (4) foothills and mountains. Basin lands consists of organic-rich saline soils adjacent to the Bay and poorly drained soils somewhat farther from the Bay. Valley land soils generally are found on gently sloping alluvial fans that surround the floodplain and basin lands. These soils, along with floodplain alluvial soils, represent the most important agricultural group of soils in California. In the Bay Area, most of the floodplain and valley land soils have been urbanized.

Terrace land soils are found along the southeastern edge of the San Francisco Bay Area at elevation 5-100 feet above the valley land. Most of these soils are moderately dense soils of neutral reaction.

Soils of the foothills and mountains that surround the Bay are formed in place through the decomposition and disintegration of the underlying parent material. The most prevalent foothills soil group is that with a moderate depth to bedrock (20-40 inches), with lesser amounts of the deep depth (>40 inches) and shallow depth (<12 inches) to bedrock soil groups being present. Moderate-depth soils generally are dark colored and fairly high in organic matter, and constitute some of the best natural grazing lands of the state. Deep soils occur in the high rainfall zones at the higher elevations in the Coast Ranges. They generally support the forested lands in the Bay Region and are characterized by acid reaction and depths to bedrock of 3-6 feet. Shallow soils occur in the medium- to low-rainfall zone. They are loamy in character and are used principally for grazing.

San Francisco Bay Seismicity. Major earthquake activity has centered along the San Andreas Fault zone, including the great San Francisco earthquake of 1906. Since that earthquake, four events of magnitude 5.0 on the Richter scale or greater have occurred in the Bay Region. The San Andreas and Hayward Faults remain active, with evidence of recent slippage along both faults.

Major earthquake activity has centered along the San Andreas Fault zone, including the great San Francisco earthquake of 1906.

Sedimentation and Erosion in San Francisco Bay. The major source of suspended sediment in the Bay is outflow from the Delta. Approximately three-quarters of the suspended sediment enters the Bay with the high winter and early spring flood flows. The highest suspended sediment and turbidity levels occur during these periods. Although much of the suspended sediment begins to aggregate at the salinity gradient and deposit in the shallow areas of Suisun and San Pablo Bays, high seasonal flows can transport incoming sediment as far as the Central and South Bays.

The major source of suspended sediment in the Bay is outflow from the Delta.

Sediments deposited in the shallower regions are resuspended by wave and wind action. Approximately 15 times as much material is resuspended each year as actually enters the Bay. Resuspension of sediment is the most important process in maintaining turbidities in the Bay from late spring through fall.

5.5.3.3 Sacramento River Region

The Sacramento River drains over 21,000 square miles (above the Feather River confluence), producing an annual average flow of 19,000 cubic feet per second (cfs). The upper watersheds of the Sacramento River Region include the drainages above Shasta Reservoir (including that portion of the Trinity River watershed, from which flows are diverted into the Bay-Delta system), the Clear Creek drainage basin west of Redding, the upper Colusa and Cache Creek watersheds west of the valley, and the Feather River and American River watersheds east of the valley. These watersheds are described in detail in Section 5.1, "Water Supply and Water Management."

The Sacramento River drains over 21,000 square miles (above the Feather River confluence), producing an annual average flow of 19,000 cubic feet per second.

Hydraulic mining on the western slopes of Sierra Nevada between 1853 and 1884 dramatically increased the sediment budgets of central Sierran streams and rivers. The addition of abundant coarse material overwhelmed the capacity of the rivers, resulting in temporary storage of the sediment in channels and floodplains, and in widespread flooding of Central Valley towns and farms. Since the end of hydraulic mining more than 100 years ago, most rivers have reestablished their original gradients, aided by trapping of the mining sediment behind dams and scouring of the channels promoted by levees built along the rivers.

The Sacramento River's hydrology has been profoundly altered by reservoir construction. At Red Bluff, the average annual flood flow was 121,000 cfs before construction of Shasta Dam (1879-1944), and 79,000 cfs after (1945-93). The 10-year flood has been reduced from 218,000 to 134,000 cfs, reducing the energy available to transport sediment in the Sacramento River. Moreover, the sediment supply to the river has been reduced by sediment trapping in reservoirs; by mining of sand and gravel from channel beds; and from artificial protection of river banks. The erosion of the river banks had supplied sediment to the channel.

The Sacramento River's hydrology has been profoundly altered by reservoir construction.

Rates of bank erosion and channel migration have declined since 1946, presumably due to change in flow and blockage of upstream sediment supply as a result of Shasta Dam, and due to the construction of downstream bank protection projects. The channel sinuosity (ratio of channel length to valley length) also has decreased.

Soils. The Sacramento River Region contains four major landform types (each with its own characteristic soils): (1) floodplain, (2) basin rim/basin floor, (3) terraces, and (4) foothills and mountains. Floodplain alluvial soils make up some of the best agricultural land in the state. Basin landforms consist of poorly drained soils, and saline and alkali soils in the valley trough and on the basin rims. These soils are used mainly for pasture, rice, and cotton. Areas above the valley floor have terrace and foothill soils, which are primarily used for grazing and timberland.

The Sacramento River Region contains four major landform types (each with its own characteristic soils): (1) floodplain, (2) basin rim/basin floor, (3) terraces, and (4) foothills and mountains.

The upper watersheds of the Sacramento Valley area mainly drain foothill soils. These soils are found on the hilly to mountainous terrain surrounding the Sacramento Valley and are formed in place through the decomposition and disintegration of the underlying parent material. The most prevalent foothill soil groups are those with a deep depth (>40 inches), shallow depth (<20 inches), and very shallow depth (<12 inches) to bedrock.

Deep soils occur in the high rainfall zones at the higher elevations in the mountains surrounding the Sacramento Valley. These areas are important timberlands that are characterized by acid reaction and depths to bedrock of 3-6 feet.

Shallow soils occur in the medium-to-low rainfall zones at lower elevations. The soils range from calcareous brown stony clay (for example, Lassen soils) to noncalcareous brown loam (for example, Vallecitos soils) and are used principally for grazing.

Very shallow soils are found on steep slopes, often at high elevations. They consist of stony clay loam or stony loam and are not useful for agriculture or timber because of their very shallow depth, steep slopes, and stony texture. As such, they also are rated very low for grazing purposes.

Geologic Conditions. The geologic provinces composing the Sacramento River Region include the Klamath Mountains, the Coast Ranges, the Cascade Range/Modoc Plateau, the Sierra Nevada, and the Central Valley.

Geomorphologic Conditions. Downstream of Red Bluff, the Sacramento River flows within a meander belt of recent alluvium. The river is characterized by an active channel, with point bars on the inside of meander bends, and is flanked by active floodplain and older terraces. While most of these features consist of easily erodible, unconsolidated alluvium, there are also outcrops of resistant, cemented alluvial units such as the Modesto and Riverbank formations.

In the channel itself, the bed is composed of gravel and sand (less gravel with distance downstream), and point bars are composed of sand. The bottomlands flanking the channel consist of silts and sands (deposited from suspended load in flood waters), commonly overlying channel gravels and sands. Higher, older surfaces consisting of (often cemented) Pleistocene deposits also are encountered.

The river channel migrates (maintaining roughly constant dimensions) across the floodplain to the limits of the meander belt, constrained only by outcrops of resistant units or artificial bank protection. As meander bends grow, they may become unstable and form cutoffs.

Since construction of Shasta Dam in the early 1940s, flood volumes on the river have been reduced, which has reduced the energy available for sediment transport. Straightening and reduced meander migration rate of the river may be associated with flow regulation due to Shasta Dam. The reduction in active channel dynamics is compounded by the physical effects of riprap bank protection structures, which typically eliminate shaded bank habitat and associated deep pools, as well as halting the natural processes of channel migration.

Since construction of Shasta Dam in the early 1940s, flood volumes on the Sacramento River have been reduced, which has reduced the energy available for sediment transport.

Sediment loads in the streams draining the upper watersheds have been artificially increased due to past and current logging and grazing practices. Both practices remove soil-stabilizing vegetation, create preferential drainageways, and promote localized soil compaction. Erosive overland flow is enhanced by the loss of vegetation and compacted soils. Larger amounts of sediment are delivered to the streams from increased rates of soil erosion and from enhanced rates of mass movement, such as landslides. During high runoff events, the sharp increases in sediment yields can lead to widespread channel aggradation, which in turn can lead to lateral migration of the channels and increased rates of landsliding.

Where reservoirs have been created by dams, most of the sediment is trapped behind the dam and, during the life of the reservoir, will not be transported downstream of the dam. Where such sediment traps are not in place, the sediment load will be transferred downstream.

Soil Subsidence. Land subsidence in the Sacramento Valley is localized and concentrated in areas of groundwater-pumping-induced overdraft. Land subsidence had exceeded 1 foot by 1973 in two main areas in the southwestern part of the valley near Davis and Zamora; however, additional subsidence since then has not been reported.

Land subsidence in the Sacramento Valley is localized and concentrated in areas of groundwater-pumping-induced overdraft.

Seismicity. The Great Valley thrust fault system forms the boundary between the Coast Ranges and the Sacramento and San Joaquin Valleys. This fault system is capable of earthquakes up to magnitude 6.8 along the west side of Sacramento Valley. The Mendocino Range west of the valley is mainly subject to seismicity from northwest-trending faults associated with the right-lateral strike-slip San Andreas Fault system.

The Great Valley thrust fault system forms the boundary between the Coast Ranges and the Sacramento and San Joaquin Valleys.

The mapped active faults of this system that are most likely to affect the upper watersheds west of the Sacramento Valley are the Green Valley, Hunting Creek, Bartlett Springs, Round Valley, and Lake Mountain Faults. These faults lie along a 150-mile-long northwest-trending zone of seismicity that is 10-45 miles west of the Sacramento Valley and extends from Suisun Bay past Lake Berryessa and Lake Pillsbury to near the latitude of Red Bluff. These faults are capable of earthquakes up to magnitude 7.1.

Active faults likely to affect the upper watersheds northeast of the Sacramento Valley, in the drainages upstream of the Shasta Reservoir, include the Mayfield-MacArthur-Hat Creek Faults, 25-85 miles north of Lake Almanor; the Gillem-Big Crack Faults near the California-Oregon border southeast of Lower Klamath Lake; and the Cedar Mountain Fault southwest of Lower Klamath Lake. These faults are part of the Sierra Nevada-Great Basin dextral shear zone and are capable of earthquakes up to magnitude 7.0. Farther northeast, the Likely Fault is judged capable of a magnitude 6.9 earthquake; in the northeast corner of the state, the Surprise Fault is capable of a magnitude 7.0 earthquake.

Active faults likely to affect the upper watersheds east of the Sacramento Valley include the Indian Valley Fault southeast of Lake Almanor and the Honey Lake Fault zone east of Lake Almanor, which is capable of a magnitude 6.9 earthquake. Surface rupture occurred in 1975 along the Cleaveland Hill Fault south of Lake Oroville. The Foothills Fault system, which borders the east side of the Sacramento and San Joaquin Valleys, is judged to be capable of a magnitude 6.5 earthquake.

In-Stream Gravel Mining. Aggregate mining occurs within many streams in the western foothills of California and in the lower foothills of the Sierra Nevada. Because of their convenient proximity to the ground surface and their location on flat land, these deposits have been mined for many years. In-stream gravel mining causes significant water quality and habitat problems due to the increased release of sediments in the river as well as the removal of soils in the areas of mining activities.

Aggregate mining occurs within many streams in the western foothills of California and in the lower foothills of the Sierra Nevada.

Wind Erosion. Soil erodibility, climatic factors, soil surface roughness, width of field, and quantity of vegetative coverage affect the susceptibility of soils to wind erosion. Wind erosion renders the soil more shallow, and can remove organic matter and needed plant nutrients. In addition, blowing soil particles can damage plants, particularly young plants. Blowing soils also can cause off-site problems such as reduced visibility and increased allergic reaction to dust.

5.5.3.4 San Joaquin River Region

The San Joaquin River drains 13,500 square miles along the western flank of the Sierra Nevada and eastern flank of the Coast Ranges, producing an average flow of 4,600 cfs near Vernalis. The San Joaquin River has three major tributaries that drain the Sierra Nevada. In downstream order, they are the Merced (drainage area 1,270 square miles, average flow 1,350 cfs), Tuolumne (1,884 square miles, average flow 2,254 cfs), and Stanislaus (980 square miles, average flow 1,400 cfs) Rivers. Precipitation is predominantly snow above 4,000 feet in the Sierra Nevada, and rain in the middle and lower elevations of the Sierra Nevada and Coast Ranges. As a result, the natural hydrology reflects a mixed runoff regime of summer snowmelt and winter-spring rainfall runoff. Another major river, the Mokelumne, enters the east Delta along with minor tributaries (including the Cosumnes and Calaveras Rivers), joining the San Joaquin River prior to its confluence with the Sacramento River. The drainage area of the Mokelumne River is 660 square miles. The hydrology of the San Joaquin River and its tributaries has been profoundly altered by dam construction and surface water diversions. So much water is diverted from Friant Dam that the mainstem San Joaquin River now goes dry at Gravelly Ford, some 30 miles downstream, except during periods of high flow. Storage of flood waters behind Friant Dam has resulted in a decline in flood magnitudes on the mainstream San Joaquin River. Similar reductions have occurred on the major tributaries, such as the Merced River. This decline has reduced the energy available to transport sediments.

The San Joaquin River drains 13,500 square miles along the western flank of the Sierra Nevada and eastern flank of the Coast Ranges, producing an average flow of 4,600 cfs near Vernalis.

Sediment supply to the river system has been reduced by catchment and trapping in reservoirs; mining of sand and gravel from channel beds; and artificial protection of river banks, the erosion of which had supplied sediment to the channel.

The floodplains of the San Joaquin River and its tributaries have been extensively modified for agricultural development, with elimination of many acres of slough and side-channel habitat.

Gravel extraction has been both extensive and intensive from the upper mainstem and the major tributaries. The combined effects of sediment trapping by upstream reservoirs and, to a lesser extent, reduced bank erosion from riprapping, have resulted in a condition of sediment-starvation. In addition, excavation of pits for aggregate production has directly transformed many reaches of the San Joaquin River and its tributaries from flowing rivers to quiescent lakes.

Gravel extraction has been both extensive and intensive from the upper mainstem and the major tributaries in the San Joaquin River Region.

Soils. The San Joaquin River Region contains four major landform types (each with its own characteristic soils): (1) floodplain, (2) basin rim/basin floor, (3) terraces, and (4) foothills and mountains. Floodplain lands contain two main soil types: alluvial soils and aeolian soils. The alluvial soils make up some of the best agricultural land in the state, whereas the aeolian soils are prone to wind erosion and are deficient in plant nutrients. Basin lands consist of poorly drained soils, and saline and alkali soils in the valley trough and on the basin rims. These soils are used mainly for pasture, rice, and cotton.

Areas above the valley floor contain terrace and foothill soils, which are primarily used for grazing and timberland.

The upper watersheds of the Sacramento and San Joaquin Valleys mainly drain foothills soils, which are found on the hilly to mountainous topography surrounding the San Joaquin Valley. Moderate depth to bedrock (20-40 inches) soils occur on both sides of the northern part of the San Joaquin Valley, where the annual rainfall is intermediate to moderately high. Deep (>40 inches) soils are the important timberlands of the area and occur in the high rainfall zones at the higher elevations in the mountains east of the valley. Shallow (<20 inches) soils, used for grazing, occur in the medium- to low-rainfall zone at lower elevations on both sides of the valley. Very shallow (<12 inches) soils are found on steep slopes, mainly at higher elevations. These soils are not useful for agriculture, grazing, or timber because of their very shallow depth, steep slopes, and stony texture.

The upper watersheds of the Sacramento and San Joaquin Valleys mainly drain foothills soils.

Geologic Conditions. The geologic provinces composing the San Joaquin River Region include the Coast Ranges, Central Valley, and Sierra Nevada.

Geomorphologic Conditions. The mainstem San Joaquin River meanders within a meander belt of recent alluvium. The river is characterized by an active channel, with point bars on the inside of meander bends, flanked by an active floodplain and older terraces. While most of these features consist of easily erodible, unconsolidated alluvial deposits, there are also outcrops of resistant, cemented alluvial units such as the Modesto and Riverbank formations.

Within the channel itself, the bed is composed of gravel and sand (less gravel with distance downstream), and point bars are composed of sand. The bottomlands flanking the channel consist of silts and sands (deposited from suspended load in flood waters), commonly overlying channel gravels and sands. Higher, older surfaces consisting of (often cemented) Pleistocene deposits also are encountered.

The river channel migrates (maintaining roughly constant dimensions) across the floodplain to the limits of the meander belt, constrained only by outcroppings of resistant units or artificial bank protection. As meander bends grow, they may become unstable and form cutoffs, leaving oxbow lakes like those visible along lower reaches of the mainstem.

Sediment loads in streams draining the upper watersheds of the San Joaquin River Region are similar to those described for the Sacramento River Region.

Soil Subsidence. After nearly two decades of little or no land subsidence, significant land subsidence recently has been detected in the San Joaquin Valley along the Delta-Mendota Canal due to increased groundwater pumping during the 1987-92 drought.

It was not until the 1920s that deep well pumping lowered the water table below the root zone of plants on the east side of the valley. Dry-farming practices were replaced with

It was not until the 1920s that deep well pumping lowered the water table below the root zone of plants on the east side of the valley.

irrigated agriculture on the west side in the 1940s, leading to the spreading and worsening of drainage problems on the west side of the valley and near the valley trough in the 1950s.

As a result of heavy pumping, groundwater levels declined by more than 300 feet in certain areas during the 1940s and 50s. The groundwater level declines resulted in significant land subsidence over large areas. Significant historical land subsidence caused by excessive groundwater pumping has been observed in the Los Banos-Kettleman Hills area, the Tulare-Wasco area, and the Arvin-Maricopa area.

Seismicity. In the San Joaquin River Region, the Great Valley thrust fault system forms the boundary between the Coast Ranges and the west boundary of the San Joaquin Valley. This fault system is capable of earthquakes up to magnitude 6.7 along the west side of San Joaquin Valley.

The Diablo Range west of the valley is mainly subject to seismicity from northwest-trending faults associated with the right-lateral strike-slip San Andreas Fault system.

The mapped active faults of this system that are most likely to affect the upper watersheds west of the San Joaquin Valley are the Ortigalita Fault and the Greenville-Marsh Creek Fault. These faults lie along northwest-trending zones of seismicity 5-20 miles west of the San Joaquin Valley; each fault is capable of earthquakes up to magnitude 6.9.

Active faults likely to affect the upper watersheds east of the San Joaquin Valley include the Foothills Fault system and major faults along the east margin of the Sierra Nevada.

Active faults likely to affect the upper watersheds east of the San Joaquin Valley include the Foothills Fault system and major faults along the east margin of the Sierra Nevada. The Foothills Fault system, which borders the east side of the northern part of the San Joaquin Valley, is judged to be capable of a magnitude 6.5 earthquake. Active faults along the east margin of the Sierra Nevada include the Owens Valley Fault, which ruptured in a magnitude 7.6 earthquake in 1872 and is within the Sierra Nevada Fault zone. Seismic activity along this fault zone can significantly affect the upper watersheds that drain to the San Joaquin Valley.

Active faults likely to affect the upper watersheds at the end of the San Joaquin Valley include the White Wolf Fault, which ruptured in 1952 with a magnitude 7.2 earthquake; the Garlock Fault, capable of a magnitude 7.3 earthquake; and several smaller faults 10-30 miles north of the White Wolf Fault.

Soil salinity problems occur primarily in the western and southern portions of the San Joaquin Valley. Soil salinity problems in the San Joaquin Valley have been, and continue to be, intensified by poor soil drainage, insufficient water supplies for adequate leaching, poor-quality (high-salinity) applied irrigation water, high water tables, and an arid climate.

Soil Salinity. Soil salinity problems occur primarily in the western and southern portions of the San Joaquin Valley. Most soils in this region were derived from marine sediments of the Coast Ranges, which contain salts and potentially toxic trace elements such as arsenic, boron, molybdenum, and selenium. Soil salinity problems in the San Joaquin Valley have been, and continue to be, intensified by poor soil drainage, insufficient water supplies for adequate leaching, poor-quality (high-salinity) applied irrigation water, high water tables, and an arid climate. A 1984 study estimated that about 2.4 million of the 7.5 million acres of irrigated cropland in the Central Valley were adversely affected by soil salinity.

Selenium Concentrations. Soil selenium is primarily a concern on the west side of the San Joaquin Valley. When soils on the west side are irrigated, selenium (along with other salts and trace elements) dissolves and leaches into the shallow groundwater. Figure 5.5-4 shows selenium levels in the top 12 inches of soil as determined by a survey in the mid 1980s. Over the past 30-40 years of irrigation, soluble selenium has been leached from the soils into the underlying shallow groundwater aquifers.

Soil selenium is primarily a concern on the west side of the San Joaquin Valley.

5.5.3.5 OTHER SWP AND CVP SERVICE AREAS

The Other SWP and CVP Service Areas region includes two distinct, noncontiguous areas: in the north, are the San Felipe Division's CVP service area and the South Bay SWP service area; to the south, are the SWP service areas. The northern section of this region encompasses parts of the central coast counties of Santa Clara, San Benito, Santa Cruz, and Monterey. The southern portion includes parts of Imperial, Los Angeles, Orange, Riverside, San Bernardino, San Diego, San Luis Obispo, Santa Barbara, and Ventura Counties.

A description of the soils and geomorphologic conditions of the Other SWP and CVP Services Areas is not included in this report because no direct impacts on geology and soils resources in this region are expected as a result of any of the Program alternatives.

5.5.4 ASSESSMENT METHODS

This programmatic assessment encompasses analyses of soil changes that could result directly from construction of new facilities or conversion of lands from one use to another; and analyses of indirect impacts of changes in policies, resources, or economics. The assessment of the effects of changes on geology and soils addresses both the direct and indirect consequences of Program actions.

Two types of analyses have been included: (1) changes in areal extent due to direct loss or conversion of soil types and geomorphologic conditions, and (2) changes in their quality. Impacts on the areal extent or quality of agricultural soils are caused by two types of Program activities: (1) conversion to different plant communities as part of a habitat-related restoration action, and (2) direct losses from the construction of project features.

Two types of analyses have been included: (1) changes in areal extent due to direct loss or conversion of soil types and geomorphologic conditions, and (2) changes in their quality.

The programmatic assessment of impacts on geology and soils evaluated potential changes to the following resource categories:

- Surface soil erosion.
- Channel, basin, shore, and shallows erosion and sedimentation.
- Soil salinity.

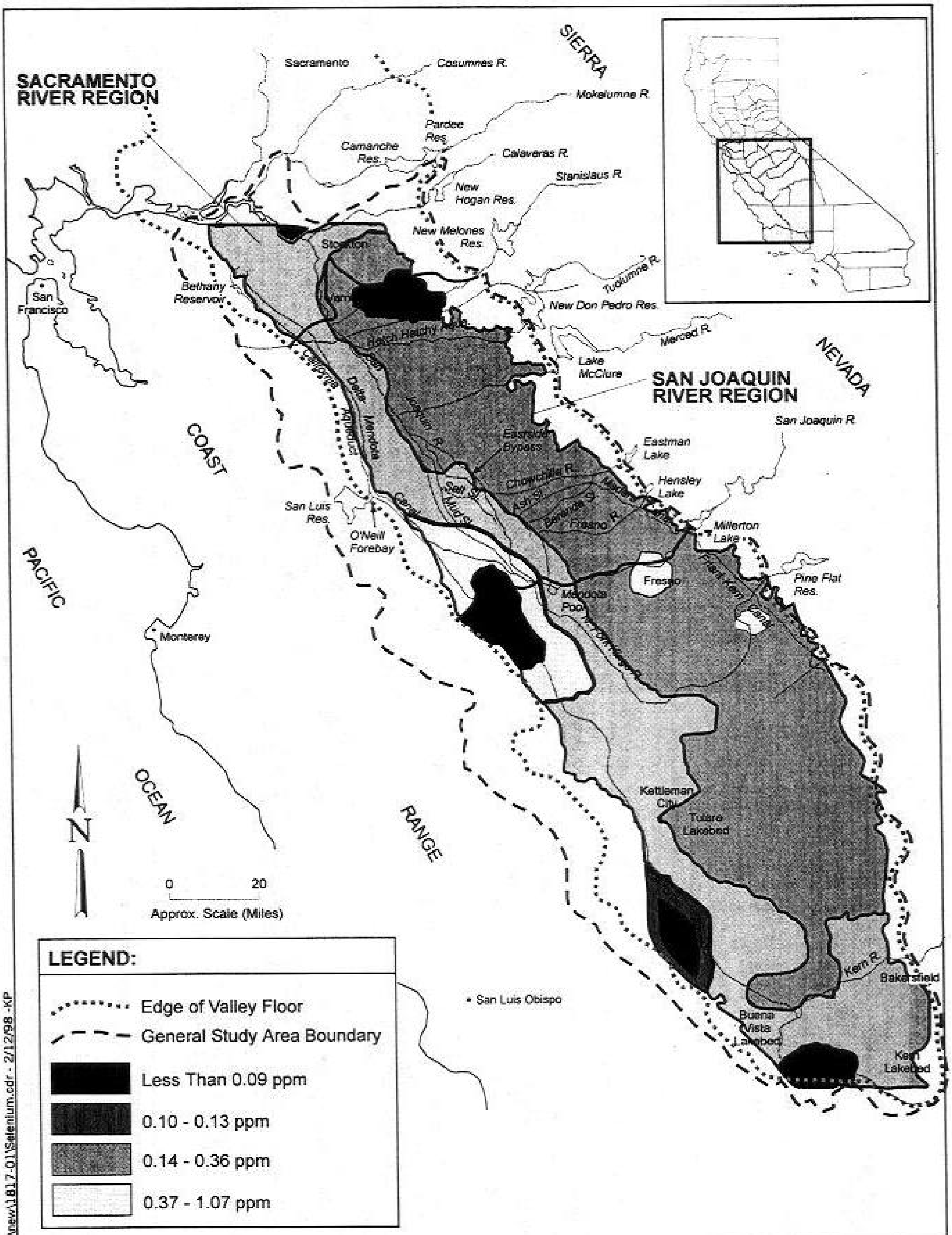

Figure 5.5-5. Selenium Concentrations

- Soil drainage characteristics.
- Subsidence caused by the mass loading from overburden and oxidation of organic content.
- Subsidence caused by groundwater withdrawals.
- Geomorphology and soils impacts due to change on land surfaces.
- Soil acreage and characteristics due to changes in land use.

Estimated changes in soil erosion are qualitative because of variability in soil type, soil erodibility, slope, and land management practices throughout the regions. Projection of soil salinity impacts was based on estimates of the affected soils and degree to which area soils would be affected by salts. The assessment of subsidence resulting from groundwater withdrawals was based on changes in the amounts and reliability of delivered water, and the resulting changes in the rates of groundwater pumping.

Estimated changes in soil erosion are qualitative because of variability in soil type, soil erodibility, slope, and land management practices throughout the regions.

5.5.5 SIGNIFICANCE CRITERIA

Impacts are considered significant if implementing a Program action would result in any of the following threshold criteria:

- Removal, filling, grading, or disturbance of soils.
- Substantial degradation of the quantity or quality of native soil types or their environmental and water quality protection characteristics in significant watersheds.
- Releases of toxic materials from soils or sediments.
- Alterations to, or drainage from, soils or substrates that create conditions that increase the potential for outbreaks of wildlife diseases.
- Adverse changes in rates of sedimentation and erosion.
- Adverse changes in soil drainage or salinity.
- Soil subsidence in increases in subsidence rates that produce adverse effects.
- Changes in soil conditions that cause undesirable seepage to adjacent lands.
- Increased potential for soil erosion by wind, waves, or currents.

- Oxidation of, or drainage from, peat soils that may cause adverse effects.
- Increased potential for erosion and mass failure-induced landslides.
- Increased potential for seismic activity or vulnerability of soil-comprised structures to seismic events.
- Disruption of natural or favorable soil profiles and horizons.
- Increased potential for damage from geologic hazards.

5.5.6 NO ACTION ALTERNATIVE

The environmental consequences of geology and soils under the No Action Alternative would be very similar to the existing conditions described in the affected environment. Channel geometry in the Delta, Bay, Sacramento River, and San Joaquin River Regions would not be altered by other than current ongoing geomorphologic, irrigation, drainage, or dredging processes. Negative trends in soil erosion, subsidence, and soil contamination are expected to continue.

Negative trends in soil erosion, subsidence, and soil contamination are expected to continue.

5.5.6.1 DELTA REGION

In the Delta Region, the No Action Alternative could result in continued problems with soil salinity, soil surface erosion and subsidence, soil selenium, and seismic susceptibility of levees to failure. Elevated levels of soil salinity in the south and west Delta could increase when compared to existing conditions for two reason: (1) the seepage and the quality of applied water caused by increasing amounts of ocean salinity intrusion, and (2) high TDS concentrations from increasing amounts of land-derived agricultural drainage. Peat oxidation of the island interior soils would continue, resulting in continued subsidence and susceptibility of the soil to wind-induced erosion. Existing high selenium concentrations could increase in the channels and applied irrigation water in the south Delta from land-derived San Joaquin Valley agricultural drainage. The susceptibility of Delta levees to seismic failure would be further increased by the continued subsidence.

In the Delta Region, the No Action Alternative could result in continued problems with soil salinity, soil surface erosion and subsidence, soil selenium, and seismic susceptibility of levees to failure.

5.5.6.2 BAY REGION

In the Bay Region, the No Action Alternative is not expected to result in any significant changes to geomorphologic or soils conditions relative to existing conditions.

5.5.6.3 SACRAMENTO RIVER REGION

In the Sacramento River Region, surface soil erosion can be expected to continue under the No Action Alternative.

5.5.6.4 SAN JOAQUIN RIVER REGION

In the San Joaquin River Region, soil salinity and selenium concentrations can be expected to increase as additional salt load is imported to the valley and leached from the soils by irrigation and natural discharge from contaminated soils on the west side. Subsidence caused by groundwater withdrawals can be expected to continue as groundwater pumping continues and increases. Surface soil erosion can be expected to continue under the No Action Alternative.

In the San Joaquin River Region, soil salinity and selenium concentrations can be expected to increase as additional salt load is imported to the valley and leached from the soils by irrigation and natural discharge from contaminated soils on the west side.

5.5.6.5 OTHER SWP AND CVP SERVICE AREAS

Geology and soils in the Other SWP and CVP Service Areas are not expected to be affected by any Program alternative. Therefore, no further discussion of geology or soils is provided for this region.

5.5.7 CONSEQUENCES: PROGRAM ELEMENTS COMMON TO ALL ALTERNATIVES

For geology and soils, the environmental consequences of the Ecosystem Restoration, Water Quality, Levee System Integrity, Water Use Efficiency, Water Transfer, and Watershed Programs and the Storage element are similar under all Program alternatives, as described below. The environmental consequences of the Conveyance element vary among Program alternatives, as described in Section 5.5.8.

5.5.7.1 DELTA REGION

Ecosystem Restoration Program

The Ecosystem Restoration Program includes habitat restoration in the Delta Region. Beneficial impacts of habitat restoration include reducing soil loss (or depletion) on Delta island interiors and levees resulting from wind erosion, wave erosion, and high-velocity

Beneficial impacts of habitat restoration include reducing soil loss (or depletion) on Delta island interiors and levees resulting from wind erosion, wave erosion, and high-velocity flows.

flows. Habitat restoration would allow for improved vegetative growth by returning humus and nutrients to the soils, and sheltering soils from the wind. The protection and maintenance of in-channel islands also would decrease wind-fetch distances over open water, thereby reducing wind-wave erosion on nearby levees.

Agreements with willing levee reclamation districts to implement modified levee and berm management practices could promote the establishment and maturation of shoreline riparian vegetation. Riparian vegetation would reduce flow velocities adjacent to the levees, thereby potentially reducing soil erosion.

Because agricultural land could be converted to habitat for ecosystem restoration, agricultural soils may undergo a transition to soils used for native habitat types. Upland terrestrial soils may be converted to hydric soils due to temporary or permanent shallow flooding to create marshland habitat. This impact is considered less than significant.

Water Quality Program

Activities proposed for the Water Quality Program would not adversely affect geology and soils in the Delta Region. Reductions in point source and nonpoint source pollutants would result in beneficial impacts in the Delta Region—by decreasing the loadings of toxic metals and organic compounds, and by removing potential sources of soil and sediment contamination, including salts and selenium.

Reductions in point source and nonpoint source pollutants would result in beneficial impacts in the Delta Region—by decreasing the loadings of toxic metals and organic compounds, and by removing potential sources of soil and sediment contamination, including salts and selenium.

Levee System Integrity Program

The Levee System Integrity Program would protect flooded Delta inboard levee slopes against wind and wave erosion with vegetation, soil, matting, or rock. Program improvements would be implemented primarily on lands used for agriculture; hence, changes in soils and geomorphologic conditions would be confined to those lands. Beneficial effects of the Levee System Integrity improvements include reducing the impact of land subsidence in the Delta, reducing the risk of levee failure, and decreasing soil salinities inboard of levees.

The Levee System Integrity Program would protect flooded Delta inboard levee slopes against wind and wave erosion with vegetation, soil, matting, or rock.

Construction of setback levees could significantly increase the floodplain width, which would result in lower flood stages and reduced peak flows, reduced soil erosion and sediment transport, and altered fluvial geomorphology.

The Levee System Integrity Program would reduce subsidence on about 14,000 acres by converting subsided land to wetlands through shallow flooding. Seismic retrofits to levees could reduce the risk of catastrophic failure, thereby reducing the risk of salinity intrusion from the ocean, which could increase salinity in the soils.

The use of agricultural soils for levee system construction would produce potentially significant adverse changes to soils in the affected areas. Agricultural soils would be covered where new setback levees are constructed. Soil erosion outboard of the levees could be reduced by habitat restoration and sediment deposition measures but would be subject to erosion during floods. The beneficial reuse of dredged material could replace soils that have been lost, prevent subsequent losses, and mitigate this impact to a less-than-significant level.

Water Use Efficiency Program

The beneficial effects of on-farm water use efficiency improvements, such as tailwater recovery ponds or installation of pressurized irrigation systems (over gravity), include greatly reducing sediment transport from fields to streams and drains. On-farm efficiency improvements could lead to increased reliance on groundwater due to irrigation needs and secondary use issues. Highly efficient irrigation requires more frequent water deliveries, some of which may not be met from surface water sources, and impoundment of tailwater leaves less surface water available to secondary users. Such users may turn to alternative sources, such as groundwater. An increased reliance on groundwater could result in localized subsidence from depletion of groundwater resources, a potentially significant adverse impact that can be mitigated to a less-than-significant level.

The beneficial effects of on-farm water use efficiency improvements, such as tailwater recovery ponds or installation of pressurized irrigation systems (over gravity), include greatly reducing sediment transport from fields to streams and drains.

Water Transfer and Watershed Programs

The Water Transfer and Watershed Programs are not expected to affect geology and soils in the Delta Region.

Storage

New groundwater and surface water storage could increase the amount of fresh water available during summer and fall. This increase in fresh water would dilute salinity in waters from tributaries with return flows that contain potentially high concentrations of salts. The additional flows in summer and fall also would reduce salinity intrusion from the ocean and transport more dissolved salts to the ocean, thereby reducing applied soil salt loads and soil salinity. This reduction is considered a beneficial impact.

New groundwater and surface water storage could increase the amount of fresh water available during summer and fall.

5.5.7.2 Bay Region

Ecosystem Restoration and Water Quality Programs

Reductions in point source and nonpoint source pollutants would result in beneficial impacts in the Bay Region.

Direct, indirect, and construction-related activities associated with the Ecosystem Restoration and Water Quality Programs could alter or displace soils in the immediate vicinity of activities; but these programs are not expected to significantly affect geology and soils in the Bay Region, including the Suisun Marsh.

As in the Delta Region, reductions in point source and nonpoint source pollutants would result in beneficial impacts in the Bay Region—by decreasing the loadings of toxic metals and organic compounds, and by removing potential sources of soil and sediment contamination, including salts and selenium.

Levee System Integrity Program

The only levee system integrity activities proposed for the Bay Region involve levee rehabilitation in the Suisun Marsh.

Currently, the Suisun Marsh is a combination of managed wetlands (seasonal and permanent) and tidally influenced areas. These managed wetlands rely on the ability to manage the flow of water onto the property to control soil salinity levels. Levee failure, particularly during the leaching cycle, would result in increased soil salinities. Increased soil salinities, in turn, adversely affect the plant communities growing in the managed wetlands.

Currently, the Suisun Marsh is a combination of managed wetlands (seasonal and permanent) and tidally influenced areas.

Levee rehabilitation in the Suisun Marsh would take place in areas that are primarily seasonally managed wetlands, and would diminish the possibility of catastrophic failure and unplanned conversion of those lands into tidally influenced lands. These activities would not adversely affect geology and soils in the Suisun Marsh.

Water Use Efficiency and Water Transfer Programs

Activities proposed for the Water Use Efficiency and Water Transfer Programs would not adversely affect geology and soils in the Bay Region.

Watershed Program

Potential beneficial effects of the coordinated watershed activities include overall lowering of sediment input to watershed streams and localized lowering of the potential for seismically induced landslides.

Potential beneficial effects of the coordinated watershed activities include overall lowering of sediment input to watershed streams and localized lowering of the potential for seismically induced landslides.

Storage

Potential geology and soils impacts associated with foreseeable changes in water availability resulting from the Storage Program are expected to be less than significant. The only potential effect would be associated with changes in sediment transport out of the Delta and into the Bay. The Preferred Program Alternative likely would cause only minor decreases in sediment transport from the Delta to the Bay.

5.5.7.3 SACRAMENTO RIVER AND SAN JOAQUIN RIVER REGIONS

Ecosystem Restoration Program

The Ecosystem Restoration Program could beneficially affect geomorphologic processes in the Sacramento River and San Joaquin River Regions. Establishment of stream meander belts would widen the area available for natural channel migration to accommodate the processes of channel erosion and deposition, and allow the stream system to respond more naturally to morphologic changes without the presently imposed physical constraints.

Gravel recruitment actions would include stockpiling gravel at strategic locations for capture by high streamflows and would allow sediment-starved reaches to mimic natural stream processes. This program would be monitored to determine the effects on channel erosion, sediment deposition, and meander processes.

The removal or reduction of seasonal diversion structures on tributaries to the Sacramento and San Joaquin Rivers would reduce sediment trapping and allow for the continued transport of sediment downstream. An adverse impact of this action would be a need for increased dredging in some areas. However, increased sediment transport also may improve areas that currently experience a net loss of sediment.

The removal or reduction of seasonal diversion structures on tributaries to the Sacramento and San Joaquin Rivers would reduce sediment trapping and allow for the continued transport of sediment downstream.

Water Quality Program

Reductions in point source and nonpoint source pollutants would benefit the Sacramento River and San Joaquin River Regions by decreasing loadings of toxic metals and organic compounds, and by reducing the concentrations of selenium and salts in these and other minor tributaries.

Levee System Integrity Program

The Levee System Integrity Program would not affect geology and soils in the Sacramento River or San Joaquin River Region.

Water Use Efficiency Program

The Water Use Efficiency Program generally would result in the same beneficial and adverse impacts identified for the Delta Region. Potential reduction of erosion from agricultural fields through use of on-farm efficiency measures would be most pronounced in the San Joaquin and Sacramento Valleys. Efficiency measures would benefit in-stream water quality by reducing sediment transport to streams and drains.

Soil salinity of agricultural lands in the San Joaquin Valley potentially can be reduced if less high-salinity water is applied to fields. In turn, this action could improve the productive capacity of some fields currently high in soil salinity.

Soil salinity of agricultural lands in the San Joaquin Valley potentially can be reduced if less high-salinity water is applied to fields. In turn, this action could improve the productive capacity of some fields currently high in soil salinity.

Conjunctive use practices involve using groundwater in combination with surface water to augment water supplies. When surplus Sacramento River or San Joaquin River water is available, it would be stored in groundwater basins (aquifers) for use when surface water availability is low. Conjunctive use of groundwater could benefit some areas of the San Joaquin Valley by reducing land subsidence that results from overdraft of groundwater reserves.

Water Transfer Program

Water transfers would affect geology and soils primarily through changes in land subsidence, erosion, and soil salinity. In addition to the source of water for a transfer, the timing, magnitude, and pathway of each transfer substantially affect the potential for significant impacts.

Water transfers would affect geology and soils primarily through changes in land subsidence, erosion, and soil salinity.

Beneficial impacts primarily include decreasing erosion and sedimentation through reduced land disturbance from fallowing; and decreasing soil salinity, relative to initial conditions, through replacement of existing irrigation water with higher quality transferred sources.

Potentially significant adverse impacts primarily include increasing wind erosion of topsoil from fallowing and the potential for land subsidence as a result of direct groundwater or groundwater-substitution-based transfers. These impacts can be mitigated to less-than-significant levels.

Watershed Program

Water quality in the Sacramento and San Joaquin Rivers would benefit from watershed activities that reduce hillslope and streambank erosion, which cause sediment loading and increased turbidity in watershed tributaries. Native vegetation could be used for bank and slope stabilization to protect ground surfaces from wind- and water-induced erosion. Road improvements and road deconstruction efforts could provide beneficial impacts by decreasing road-related erosion and reducing the potential for landslides on over-steepened slopes.

Water quality in the Sacramento and San Joaquin Rivers would benefit from watershed activities that reduce hillslope and streambank erosion, which cause sediment loading and increased turbidity in watershed tributaries.

Potentially significant adverse impacts associated with upper watershed activities could include short-term soil erosion and increased sediment deposition during the construction of stream and watershed restoration projects or roadway improvements. Compaction of soil by heavy equipment during construction would temporarily affect the physical characteristics of the soil. These impacts can be mitigated to less-than-significant levels.

Long-term post-construction effects are expected to be beneficial. These effects include reducing sediment erosion and excess sedimentation in streams caused by poorly managed timber harvesting, livestock grazing, and other land use activities. Most watershed restoration efforts would include a revegetation component to reduce erosion, stabilize hazardous slopes, and provide terrestrial or aquatic habitat.

Storage

Construction of storage facilities would result in potentially significant adverse impacts because of local ground disturbances and inundation, the extent of which would depend on the type and size of storage facilities enlarged or constructed, construction methods, and sites selected. Reservoir construction also would require construction of access roads and dams. Increased erosion could occur on areas cleared for storage facilities or access roads. Compaction of soil by heavy equipment during construction would temporarily affect the physical characteristics of the soil, including decreasing permeability and increasing runoff.

Compaction of soil by heavy equipment during construction would temporarily affect the physical characteristics of the soil, including decreasing perme-ability and increasing runoff.

Any expansion of existing storage facilities could potentially increase downstream stream erosion capabilities and change downstream geomorphologic characteristics. Reductions of stream bedload would be greatest during high-flow events. Off-stream storage sites would not directly affect in-stream sediment transport but may diminish flows in local stream channels due to their placement across minor drainages. Diversions of water to off-stream storage facilities potentially could adversely affect downstream geomorphology. This impact is expected to be less than significant as diversions would be intermittent and would occur during high-flow periods. Wind- and wave-generated erosion along the shoreline of the reservoir could cause a potentially significant impact by increasing bank erosion and sedimentation at the site. The potential for landslides in areas around a reservoir may be increased by saturation of adjacent geologic strata as the reservoir is filled. The significance of this impact cannot be determined at the programmatic level and will be addressed in future site-specific documents.

5.5.8 CONSEQUENCES: PROGRAM ELEMENTS THAT DIFFER AMONG ALTERNATIVES

For geology and soils resources, the Conveyance element results in environmental consequences that differ among the alternatives, as described below.

5.5.8.1 PREFERRED PROGRAM ALTERNATIVE

Impacts on geology and soils would include increased short-term soil erosion and soil compaction associated with construction activities.

This section includes a description of the consequences of a pilot diversion project. If the pilot project is not built, these consequences would not be associated with the Preferred Program Alternative.

Under the Preferred Program Alternative, Conveyance elements include constructing a screened intake, modifying existing channels, and constructing a pilot diversion structure near Hood. Impacts on geology and soils would include increased short-term soil erosion and soil compaction associated with construction activities. Impacts caused by dredging on the Mokelume River are considered less than significant.

The potential for increased erosion of channel and levee soils is considered less than significant.

Increased pumping of water out of the Delta could result in increased flows during some months. The magnitude of change in flow velocities would likely be negligible relative to existing flows and therefore would not adversely affect soil erosion or sediment transport processes. Consequently, the potential for increased erosion of channel and levee soils is considered less than significant.

Proposed flow changes would not be sufficiently large or prolonged to cause significant changes in fluvial geomorph-ologic processes in Delta channels.

Changes in project operations would not significantly affect geology and soils. Proposed flow changes would not be sufficiently large or prolonged to cause significant changes in fluvial geomorphologic processes in Delta channels. No resultant changes in land use practices would affect these resources from the proposed operational measures.

5.5.8.2 ALTERNATIVE 1

Effects on geology and soils under Alternative 1 would be similar to those described for the Preferred Program Alternative, except that no pilot diversion facility near Hood would be constructed. Consequently, less construction-related geology and soils impacts are associated with Alternative 1 than with any other Program alternative.

5.5.8.3 ALTERNATIVE 2

Effects on geology and soils under Alternative 2 would be similar to those described for the Preferred Program Alternative. The primary difference between the two alternatives is the size of the diversion facility at Hood. Because the diversion facility could be larger than that proposed under the Preferred Program Alternative, the construction-related impacts on geology and soils could be greater under Alternative 2 than under the Preferred Program Alternative or Alternative 1.

5.5.8.4 ALTERNATIVE 3

In addition to the Conveyance components listed for the Preferred Program Alternative, Alternative 3 includes the possibility of constructing an isolated facility. Because of the isolated facility, additional construction-related impacts on geology and soils would be greatest under Alternative 3.

Because of the isolated facility, construction-related impacts on geology and soils would be greatest under Alternative 3.

5.5.9 PROGRAM ALTERNATIVES COMPARED TO EXISTING CONDITIONS

This section presents the comparison of the Preferred Program Alternative and Alternatives 1, 2, and 3 to existing conditions. This programmatic analysis found that the potentially beneficial and adverse impacts from implementing any of the Program alternatives when compared to existing conditions were the same impacts as those identified in Sections 5.5.7 and 5.5.8, which compare the Program alternatives to the No Action Alternative.

At the programmatic level, the comparison of the Program alternatives to existing conditions did not identify any additional potentially significant environmental consequences than were identified in the comparison of the Program alternatives to the No Action Alternative.

The following potentially significant environmental consequences are associated with the Preferred Program Alternative:

- Increased conversion of agricultural land soils for levee system construction and increased potential for erosion on outboard slope of levees.
- Potential for increases in local subsidence from potential increased reliance on groundwater use.
- Potential for increases in wind and soil erosion and soil salinity due to fallowed agricultural lands.
- Increased construction-related short-term soil erosion, and increased sediment deposition or soil compaction from heavy equipment.
- Potential changes to downstream geomorphology from enlarging existing storage facilities.
- Ground disturbance, inundation, and shoreline wind- and wave-generated erosion from new storage facilities.

No potentially significant unavoidable impacts on geology and soils are associated with the Preferred Program Alternative.

5.5.10 ADDITIONAL IMPACT ANALYSIS

Cumulative Impacts. For a summary comparison of cumulative impacts of all resource categories, please refer to Chapter 3. For a description of the projects and programs that contributed to this cumulative impact analysis, please see Attachment A.

All projects considered in the cumulative impact analysis involve both beneficial and adverse impacts on geology and soils. These impacts could add to or detract from the potential impacts on geology and soils that are associated with implementing the Preferred Program Alternative. Cumulative impacts on geologic and soil conditions could result from the incremental impacts of ground disturbance, altered fluvial geomorphology, soil subsidence, inundation, seismic vulnerability, and direct transportation of materials for construction. These actions are associated with the Program and other ongoing projects undertaken by other agencies or persons. Actions under the Preferred Program Alternative could be coordinated with present and proposed projects, thereby reducing the extent of the cumulative impacts. All other impacts on geology and soils resources that are associated with the Program can be mitigated to a less-than-significant level and therefore are not considered potentially significant cumulative impacts.

Cumulative impacts on geologic and soil conditions could result from the incremental impacts of ground disturbance, altered fluvial geomorphology, soil subsidence, inundation, seismic vulnerability, and direct transportation of materials for construction.

Growth-Inducing Impacts. If improvements in water supply are caused by the Preferred Program Alternative, the Preferred Program Alternative could induce growth, depending on how the additional water supply was used. If the additional water was used to expand agricultural production or urban housing development, the proposed action would foster economic and population growth. Expansion of agricultural production and population could affect geology and soils resources, but the significance of the impact would depend on where the agricultural or population growth occurred and how it was managed, and cannot be determined at the programmatic level.

Short- and Long-Term Relationships. The Preferred Program Alternative generally would maintain and enhance the long-term productivity of geology and soils resources but may cause adverse impacts on these resources from short-term uses of the environment.

Overall benefits to the long-term productivity of geology and soils resources would result from Program actions. Benefits resulting from reduced erosion, reduced soil salinity, and reduced soil subsidence generally would outweigh the short-term adverse impacts.

Benefits resulting from reduced erosion, reduced soil salinity, and reduced soil subsidence generally would outweigh the short-term adverse impacts on geology and soils.

Most short-term impacts are related to construction and would cease when construction is complete. Where possible, avoidance and mitigation measures would be implemented as a standard course of action to lessen impacts. The potentially significant long-term impacts on soils in the form of ground disturbance, inundation, and changes to downstream geomorphology from construction of storage facilities were identified in this impact analysis.

Irreversible and Irretrievable Commitments. The Storage and Conveyance elements in the Preferred Program Alternative can be considered to cause significant irreversible changes in geologic and soil conditions. Avoidance and mitigation measures could be implemented to lessen adverse effects, but changes would be experienced by future generations. The long-term beneficial irreversible changes include reduced soil erosion and salinity. The long-term adverse irreversible changes include ground disturbance, inundation, and changes to downstream geomorphology from construction of new storage facilities or enlargement of existing storage facilities. Storage and Conveyance elements could result in the irretrievable commitment of resources, such as construction materials, labor, energy resources, and land conversion.

5.5.11 MITIGATION STRATEGIES

These mitigation strategies will be considered during project planning and development. Specific mitigation measures will be adopted, consistent with the Program goals and objectives and the purposes of site-specific projects. Not all mitigation strategies will be applicable to all projects because site-specific projects will vary in purpose, location, and timing.

The following mitigation strategies will be considered in future site-specific documents:

Mitigation strategies include measures to minimize impacts related to soil subsidence, soil erosion, soil salinity, and soil transport.

- Monitoring groundwater levels and subsidence in areas of increased reliance on groundwater resources and regulating withdrawal rates at levels below those that cause subsidence.
- Minimizing or avoiding direct groundwater transfers or groundwater substitution transfers from regions: (1) experiencing long-term overdraft, (2) where subsidence historically has occurred, or (3) where local extensometers indicate that subsidence rates are increasing.
- Protecting flooded Delta island inboard levee slopes against wind and wave erosion with vegetation, soil matting, or rock.
- Protecting exposed soils with mulches, geotextiles, and vegetative ground covers to the extent possible during and after project construction activities to minimize soil loss.
- Implementing erosion control measures and bank stabilization projects where needed. Measures can include grading the site to avoid acceleration and concentration of

overland flows, using silt fences or hay bales to trap sediment, and revegetating areas with native riparian plants and wet meadow grasses.

- Increasing sediment deposition and providing substrate for new habitat by planting terrestrial and aquatic vegetation.
- Measuring channel morphology over time to monitor changes due to reoperation of SWP and CVP flows and implementing erosion control measures where needed.
- Re-using dredged materials to reduce or replace soil loss.
- Leaving crop stubble from previous growing season in place while fallowing and employing cultivation methods that will cause the least amount of disturbance to minimize erosion of surface soils.
- Limiting the salinity of replacement water, relative to local conditions, in water transfers.
- Ensuring that the volume of irrigation water used is sufficient to flush accumulated salts from the root zone.
- Operating new storage facilities to minimize sediment trapping and transport in rivers and tributaries.
- Retrofitting soil-comprised structures to seismic events with shock-absorbing devices and materials in areas of seismic vulnerability, wherever possible.
- Preparing and implementing best construction management plans.
- Preparing and implementing a water quality and soils monitoring program.
- Preparing and implementing construction mitigation plans.
- Preparing and implementing contingency plans for wetland and marshland restoration.
- Modifying storage facility operations to maintain variability in downstream flow rates.
- Controlling boat traffic in order to reduce boat wakes to levels that will not cause levee or bank erosion.

5.5.12 POTENTIALLY SIGNIFICANT UNAVOIDABLE IMPACTS

No potentially significant unavoidable impacts on geology and soils are associated with the Preferred Program Alternative.

No potentially significant unavoidable impacts on geology and soils are associated with the Preferred Program Alternative.